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To cite this article: S V Parshin and A A Parshina 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **560** 012083

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# Research and improvement of the process of two-stage profiling of tubes for special purposes

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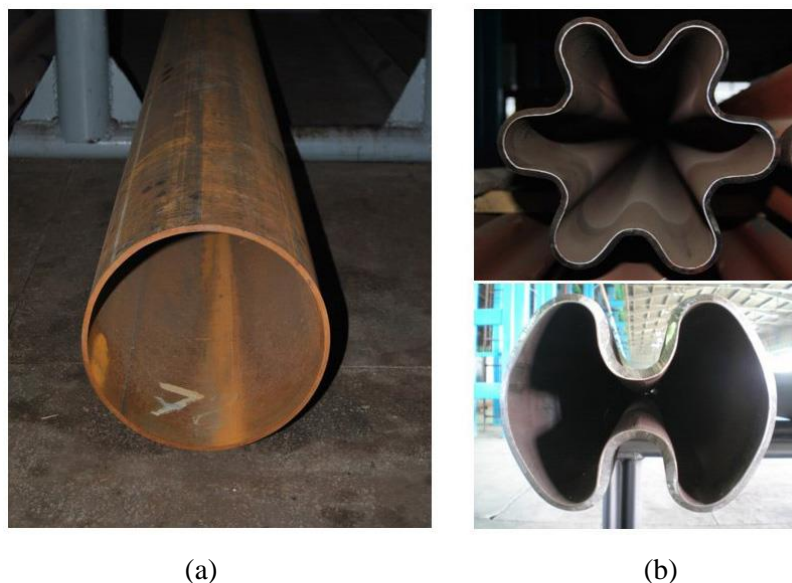
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**Abstract.** Roll-forming process is used in manufacturing multi-beam oil tubes, while reducing their outer profile diameter and forming star-like profile. In this paper a steel tubes are studied with a drawing and pushing processes. This study gets into different issues including elastoplastic behavior, contacts and friction using finite element analysis. In simulations, a plane symmetric steady-state model is used. Numerical results are compared with experimental results. A better understanding and modelling of the behavior of materials lead to a new form of roller tool with significant advantages.

## 1. Introduction

A significant part of the profile tubes of the usual and widely applicable range are tubes with a constant wall thickness, obtained from a plain tube by bending the wall (figure 1) [1,2]. When profiling, many of these tubes experience large deformations of the wall, while for tubes with concave sections of the profile there is a significant change in the wall radius, accompanied by the appearance of tensile stresses on the inner surface of the tube.



**Figure 1.** Tube profiling: (a) blank tube, (b) profile tubes, obtained by bending the wall.



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## 2. Study of a subject

The main methods of profiling such tubes are pulling or pushing the tube through a profile die or roller tool. With these methods, significant deformations occur in non-contact zones, their length is significant, and the bending radius is difficult to predict.

Predicting tube behavior requires the introduction of a number of parameters and boundary conditions, such as the exact shape of the tool and blank tube, friction parameters, material properties (taking into account the nonlinear elastic-plastic behavior of the tube, for example, the elastic aftereffect at the exit of the profiling tool).

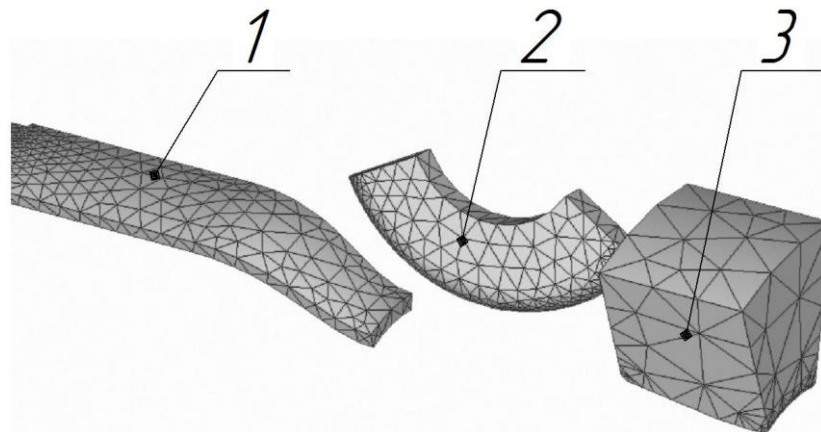
## 3. Results and Discussion

The only practical way to solve such a complex problem is an approximate numerical one. The finite-element implementation of the method — in standard CAE application packages — allows one to determine the parameters of the stress-strain state, the shape of the finished tube, predict defects and deviations of the profile shape [3-6].

In addition to the direct possibilities of the design process, finite element solution allows to predict and improve the shape of the tool due to the iterative process of its selection for any parameter, for example, the drawing force or the value of the unit pressure on the tool. One of the ways to reduce the wear rate of a tool with sliding friction (i.e. shaped dies) is to achieve the most uniform pressure distribution on the contact of tube and die. This can be achieved, for example, due to the closest match of the shape and radii of free bending of the tube with those for the tool.

Reducing the number of free deformation zones potentially brings the stress state scheme to an ideal one with a uniform compression, which should potentially increase the ductility of the metal. In turn, an increase in plasticity favorably affects the exhaustion of the resource of plasticity of the material in the hazardous zones of the profile.

Volumetric solid-state and finite-element models was built for the solution (Figure 2).



**Figure 2.** Scheme of the model. 1 – tube model with lead-in area, 2 – roller model, 3 – core ring model.

The model corresponds to the real case of smooth tube profiling with a lead-in section in a block of 6 profiling rollers with additional profiling in a conic ring. The diameter of the blank tube – 245 mm, wall thickness – 8 mm. The model has a set of boundary conditions corresponding to pushing the tube by a distance equal to the length of the tube section through the roller block and the die.

The rollers are assumed to be non-deformable, the rolling are modeled by the corresponding coefficient of friction. A die accepted as undeformable and fixed. The tube material is set to 1010 steel. The properties were set in the form of a hardening curve with a piecewise description method (stress and strain correspondence table). Reference curve is a handbook data. The material model and the

calculation is elastoplastic, taking into account the elastic aftereffect (spring back) of the tube after leaving the profiling tool.

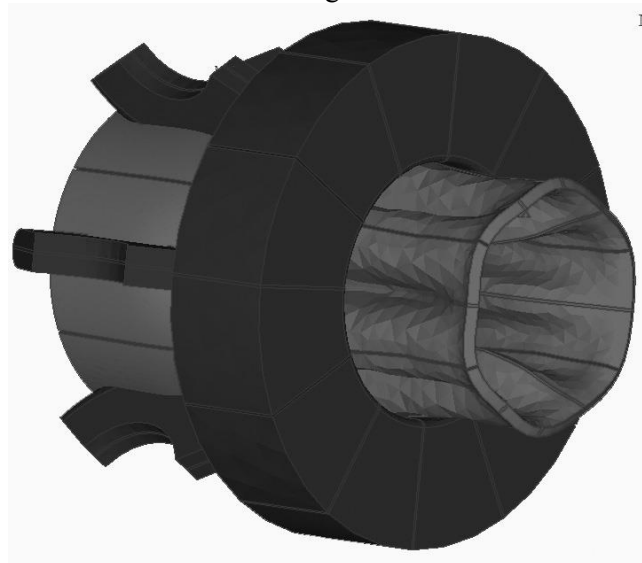
Due to the complexity of the geometry of a solid model, according to open source recommendations, a type of finite elements was chosen for modeling was a tetrahedra with intermediate nodes. The meshing density was selected and model was meshed. For the tube model, the following grid density was chosen - on average, 1 element per tube wall thickness, with a grid thickening of up to 2 elements per wall thickness in the area of the connection cones. For the model of rollers, the control of the mesh was carried out visually by the “smoothness” of the resulting roller surface, for dies, by the smoothness of roundings at the entrance to the profiling section.

The contact interaction parameters are set. The contact of the outer surface of the tube with the outer surface of the roller and the inner surface of the ring is set. The coefficient of friction is assumed to be 0.15 by reference and experimental data [7-10].

The average calculation took about 1 hour on a workstation with a Core I7 3.6 GHz processor with 16 Gb RAM.

According to the results of a series of calculations (more than 20 design cases), trial ones, carried out with a zero friction coefficient, the meshing was adjusted – the elements are refined on the rolling surface of the roller.

The final design configuration was carried out with a real friction coefficient and included an additional lead-in part on the front section of the tube. The scheme of a finite element model is shown in figure 2. The complete full model is shown in Figure 3



**Figure 3.** complete design model after profiling, completed with regard to symmetry.

It was found that the required configuration of the resulting tube can be obtained with a different ratio of the radial installation depth of the rollers and the diameter of the calibrating section of the profiling ring. Thus, two extreme cases are possible:

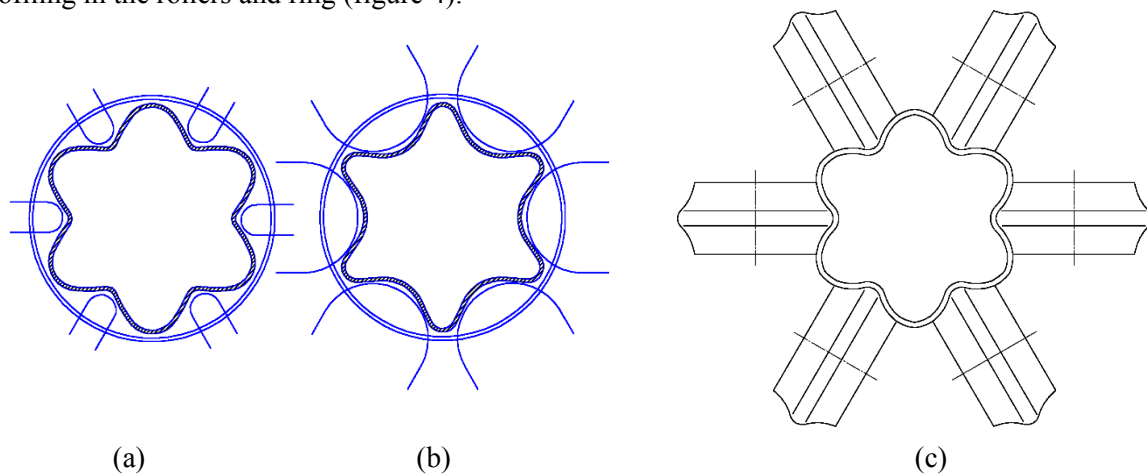
1. At first, the tube is profiled by the rollers only until a slight bulge is formed on the inner surface, which corresponds to some “loss of stability” of the wall, and then it is profiled to the required configuration by pulling or pushing it through the ring;
2. Complete deformation by the rollers to a size close to the desired. Then the tube is calibrated using a profiling ring with a small amount of plastic deformation. Such a scheme, however, has a limitation on the depth of deformation in the block of rollers, associated with the rolling friction angle of the rollers - which means that there is a limiting value for the depth of profiling.

The actual ratios of the profiling depth of the rollers and the diameter values of the calibrating section of the profiling ring lie in the range between the considered limiting cases, which gives the technology developer a field for varying these parameters.

For the considered sizes of tubes and its material, a rational technology seems to be in which the pipe is profiled in a block of 6 rollers installed at a deformation depth of 30 mm relative to the initial profile of the blank tube, and additional shaping to the required depth of 32 mm is performed in a ring. The use of rollers reduces friction by rolling, and the core ring maintains a constant section shape at the front and rear ends of the tube.

#### 4. Conclusion

On the basis of the conducted research, it is possible to obtain a tube from a given material, characterized by increased reliability (by varying the width of the roller), which fits into the specified size framework due to variation by the loading scheme (drawing or pushing), the shape of the tool and the ratio of profiling in the rollers and ring (figure 4).



**Figure 4.** Tube profiling with rollers: a- narrow, b - wide toroidal, c - wide with a curved surface.

#### Acknowledgments

The reported study was funded by the state budget themes “Theoretical foundations for the development of new processes and machines for improving the competitiveness of manufactured products”, “Developing the theoretical foundations of technologies and equipment for producing new types of metal products”.

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